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Device and process for generation of a partly synthesized high-quality signal for acceleration of an armature of an electric drive

In order to design high-quality position or speed control for a rotary or linear electric drive it has been customary in the past to control the components directly generating torque or force in the innermost loop, that is, in cascade control [1;2]. The most recent developments [3;4] have shown that on the other hand it is highly advantageous not to control the torque or force generating components of the current volume indicators indirectly but to guide the acceleration of the part propelled, that is, in cascade control. In the case of rotary drives this is the spin of the rotor and in the case of linear drives the linear acceleration of the armature. Hence use of an accelerometer is required for registration of these values, for example, an accelerometer which operates on the ~~Ferraris principle~~ [3;4;5]. For one thing, however, ~~this accelerometer on the whole is characterized by a delay in measurement, albeit a small one.~~ For another, this accelerometer can never be completely rigidly connected to the place engaged by rotary thrust in the case of a rotary drive or by linear thrust in the case of a linear drive. The result of these two facts is that loop limit cycles and/or self-excited oscillations are formed in the cascade control loop for the acceleration [4]. Unless these limit cycles and/or self-excited oscillations are prevented, use of such a cascade control loop is not successful for high-quality position or speed control. A process for suppression of these limit cycles and/or self-excited oscillations in the cascade control loop for acceleration has been proposed for rotary drives [4]. However, this process has the disadvantage that its application is

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extremely costly and in addition that it reacts with extreme sensitivity to fluctuations in the parameters of the drive.

A partly synthesized signal of high dynamic quality for acceleration of an armature of an electric drive can be generated by means of the device claimed for the invention as proposed here. Cascade control of acceleration can be achieved by means of this signal, to a great extent independently of the parameters of the drive, while limit cycles and/or self-excited oscillations are prevented in this cascade acceleration control loop.

A partly synthesized signal of high dynamic quality can be generated with a device as described in Claims 1-12.

For the purpose of generating a high-quality signal for acceleration of an electric drive, first the acceleration signal $b_m = \alpha F_g(p)$, in which $F_g(p)$ describes the measurement transfer function, is registered and then the torque m or the propulsive force f as substitute acceleration signal $b_{Em} = m$ or $b_{Em} = f$ and, all losses arising throughout propulsion being disregarded and the basis adopted being that of an absolutely rigid connection of the surface engaged by the thrust of the drive to the place at which the effect used for registration of acceleration is used, is scaled so that the relation $b_m = \alpha F_g(p) - b_{Em} F_g(p)$ is satisfied. The acceleration signal $b_m = \alpha F_g(p)$ is taken to a low-pass filter with the low-pass transfer function $FT(p)$; hence the signal $x = b_m - FT(p)$ is present at the output of the filter and the substitute acceleration signal becomes a high-pass filter with the high-pass transfer function $FH(p) = FT(0) - FT(p)$ adjacent to the output of which is the signal $y = b_{Em} = \alpha F_g(p)$, adjacent to the output of which is the signal $y = b_{Em} = \alpha F_g(p) [FT(0) - FT(p) F_g(p)]$. Lastly, the synthesized signal $z + y$ is formed; it is used as a substitute signal of high

dynamic quality for the instantaneous armature acceleration value in automatic control of the drive.

For this purpose, in the case of rotary current propulsion the rotary acceleration α of the rotated armature is registered metrologically by an accelerometer [3;4;5] connected to this armature and preferably operating on the Ferraris principle, and is consequently available as measured acceleration signal $bm - \alpha$

$Fg(p)$. $Fg(p)$, with $Fg(0) = 1$, here represents the so-called measurement transfer function of the accelerometer. The torque m of the drive, hereafter designated as substitute acceleration signal $bE = m$, is also registered metrologically and accordingly is available as measured substitute acceleration signal $bE = m$. As is to be immediately perceived, use may of course be made, without impairing the operation of the device claimed for the invention, in place of the torque m of the drive, also directly of the torque-forming transverse-current components iq of the current volume indicator of the rotary current fed winding of the drive as substitute acceleration signal $bE = iq$. In what follows, as is customary in metrology, it is assumed that on the one hand the measured acceleration signal bm and on the other the measured substitute acceleration signal bEm , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $bm = \alpha \cdot Fg(p) = bEm \cdot Fg(p)$ is satisfied. The measured acceleration signal bm is delivered to the input of a low-pass filter with the low-pass transfer function $FT(p)$, $FT(0)$ preferably equaling 1. Hence the signal $x = bm \cdot FT(p)$ can be received at the output of the low-pass

filter. The measured substitute acceleration signal bEm is delivered to the input of a high-pass filter with high-pass transfer function $FH(p) = FT(0) - FT(p) \cdot Fg(p)$. Consequently, the signal $y = bEm [FT(0) - FT(p) \cdot Fg(p)]$ may be received at this high-pass filter. A signal $z = bm \cdot FT(p) + bEm [FT(0) - FT(p) \cdot Fg(p)]$ is now formed in accordance with the relation $z = x + y$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question.

In the case of a traveling-wave drive the linear acceleration α of an armature in linear movement is metrologically registered by means of an accelerometer mechanically connected to this armature, one preferably operated on the Ferraris principle transposed to linear movement, and is accordingly available as measured acceleration signal $bm = \alpha \cdot Fg(p)$. In this instance $Fg(p)$, with $Fg(0) = 1$, represents the so-called measurement transfer function of the accelerometer. The linear force f of the drive, to be designated in what follows as substitute acceleration signal $bE = f$, is also registered metrologically and is accordingly available as measured substitute acceleration signal bEm . As is to be immediately perceived, without impairing the operation of the device claimed for the invention, the transverse-current component iq immediately forming the linear force of the current volume indicator of the multiphase current-fed winding of the drive may be used as substitute acceleration signal $bE = iq$. It is assumed in what follows, as is customary in control engineering, that both the measured acceleration signal bm and the substitute acceleration signal bEm , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid

connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $b_m = \alpha \cdot F_g(p) = b_{Em} \cdot F_g(p)$ is satisfied. The measured acceleration signal b_m is delivered to the input of a low-pass filter with the low-pass transfer function $FT(p)$, $FT(0)$ preferably equaling 1. Hence the signal $x = b_m \cdot FT(p)$ can be received at the output of the low-pass filter. The measured substitute acceleration signal b_{Em} is delivered to the input of a high-pass filter with high-pass transfer function $FH(p) = FT(0) - FT(p) \cdot F_g(p)$. Consequently, the signal $y = b_{Em} \cdot [FT(0) - FT(p) \cdot F_g(p)]$ may be received at the output of this high-pass filter. A signal $z = b_m \cdot FT(p) + b_{Em} \cdot [FT(0) - FT(p) \cdot F_g(p)]$ is now formed in accordance with the relation $z = x + y$. This synthesized signal is subsequently used as a very high-quality dynamic substitute for the undelayed instantaneous value of rotary acceleration α of the rotated armature in automatic control of the drive in question.

In the case of direct-current propulsion the rotary acceleration α of the rotated armature is registered metrologically by an accelerometer [3;4;5] connected to this armature and preferably operating on the Ferraris principle, and is consequently available as measured acceleration signal $b_m - \alpha \cdot F_g(p)$. $F_g(p)$, with $F_g(0) = 1$, here represents the so-called measurement transfer function of the accelerometer. The torque m of the drive, hereafter designated as substitute acceleration signal $b_E = m$, is also registered metrologically and accordingly is available as measured substitute acceleration signal b_{Em} . As is to be perceived immediately, use may of course be made, without impairing the operation of the device claimed for the

invention, in place of the torque m of the drive, also directly of the armature current i_a of the direct-current fed winding of the drive as substitute acceleration signal $b_E = i_a$. In what follows, as is customary in metrology, it is assumed that on the one hand the measured acceleration signal b_m and on the other the measured substitute acceleration signal b_{Em} , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $b_m = \alpha F_g(p) = b_{Em} F_g(p)$ is satisfied. The measured acceleration signal b_m is delivered to the input of a low-pass filter with the low-pass transfer function $FT(p)$, $FT(0)$ preferably equaling 1. Hence the signal $x = b_m FT(p)$ can be received at the output of the low-pass filter. The measured substitute acceleration signal b_{Em} is delivered to the input of a high-pass filter with high-pass transfer function $FH(p) = FT(0) - FT(p) F_g(p)$. Consequently, the signal $y = b_{Em} [FT(0) - FT(p) F_g(p)]$ may be received at this high-pass filter. A signal $z = b_m FT(p) + b_{Em} [FT(0) - FT(p) F_g(p)]$ is now formed in accordance with the relation $z = x + y$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question.

The device and the process for obtaining a partly synthesized signal of high dynamic value for acceleration of the armature of a machine is explained in detail in what follows on the basis of an example of a separately excited direct-current machine and with reference to the drawings in Figures 1 to 4.

It is advantageous for design of high-quality position or speed control for a separately excited direct-current machine to control rotary acceleration of the armature rather than the armature current in the innermost loop. For this purpose the rotary acceleration α of the rotor is registered by an accelerometer, preferably one operating on the Ferraris principle, and is accordingly available as measured rotary acceleration $b_m = \alpha \cdot F_g(p)$. Block 1 (see Figures 1, 2, 3, and 4) with transfer function $F_g(p)$, with $F_g(0) = 1$, describes the so-called measurement frequency response of the accelerometer. The torque m of the drive, which in what follows is designated as substitute acceleration signal $b_E = m$, is also registered metrologically and accordingly is available as measured substitute acceleration signal b_{Em} . Armature current I_a of the direct-current-fed armature winding of the drive may, of course, also be used as substitute acceleration signal $b_E = i_a$ in place of the moment m of the drive. In what follows, as is customary in control engineering, it is assumed that on the one hand the measured acceleration signal b_m and on the other the measured substitute acceleration signal b_{Em} , all losses occurring in the drive in question being disregarded and a mechanically absolutely rigid connection of the surface of the armature rotated engaged by the torque to the position of the rotated part of the rotary acceleration meter at which the effect used for registration of acceleration is generated being taken as a basis, is each scaled so that the relation $b_m = \alpha \cdot F_g(p) = b_{Em} \cdot F_g(p)$ is satisfied. The measured acceleration signal b_m is delivered to the input of a low-pass filter 2 (see Figures 1, 2, 3, and 4) with the low-pass transfer function $F_T(p)$, $F_T(0)$ preferably equaling 1. Hence the signal $x = b_m \cdot F_T(p)$ can be received at the output of the low-pass filter. The measured substitute acceleration signal i_{bm} is delivered to the input of a high-pass filter 3 (see Figures 1 and

2) with high-pass transfer function $FH(p) = FT(0) - FT(p)$ $Fg(p)$. Consequently, the signal $y = bEm [FT(0) - FT(p)]$ $Fg(p)]$ may be received at this high-pass filter. A signal $z = bm$ $FT(p) + bEm [FT(0) - FT(p) Fg(p)]$ is now formed in accordance with the relation $z = x + y$. This synthesized signal is subsequently used as a very high-quality dynamic substitute as the undelayed instantaneous value of the rotary acceleration α of the rotated armature in automatic control of the drive in question. The difference between the set value α_{soll} assigned by a superimposed control system and the synthesized signal z is delivered to a suitable control unit 4 as control difference (see Figure 1). Delay of the measurement transfer function $Fg(p)$ and the considerable disturbance of the transfer function $FM(p)$ are eliminated from the control frequency response, which is of decisive importance for stability, possible limiting cycles, and self-excited oscillations. The last-named transfer function, $FM(p)$, describes the mechanical frequency response between the surface of the armature moved which is engaged by the thrust of the drive and the position of the moved part of the accelerometer at which the effect used for registration of acceleration is generated. The low-pass filter with low-pass transfer function $Fy(p)$ almost entirely eliminates the influence of this mechanical frequency response. So long as transfer function $FM(p)$ does not deviate significantly from value 1, damping of the low-pass filter does not exhibit significant values. But starting with the limit frequency of the low-pass filter the damping rises sharply, so that the unavoidable resonance step-ups of the mechanical frequency response virtually exert no more influence. The delay of the acceleration signal bm by the measurement transfer function $Fg(p)$ and the delay additionally caused by the low-pass filter are entirely eliminated by signal $y = bEm FH(p)$ at the output of the high-pass filter in the frequency response.

in question of the control loop formed by means of the synthesized signal z.

The procedure claimed for the invention as presented is also described by the block diagram in Figure 1. The first-order delay element 5 (see Figures, 1,2,3, and 4) with amplification VR and time constant TE describes the delayed reaction of the armature current ia to change in voltage at the input of the delay element.

In a preferred embodiment the output voltage of the pulse inverter which feeds the armature winding of the drive is derived directly from a two-point control loop [6], on the principle of the discrete-time switching condition control with a clock frequency $f_A = 1/TA$ in the 100-kHz range. Consequently, in Figure 2 the controller 4 is replaced by the two-point element 6, a scanning element 7 with scanning frequency $f_A = 1/TA$, and a zero-order holding element 8. Amplifications V and -V in the two-point element 6 take the ratio of converter output voltage to rated voltage of the machine into account. The scanning element 7 and the zero-order holding element 8 allow for the effect of discrete-time switching condition control. In this embodiment of the device claimed for the invention the limit frequency selected for the low-pass filter 2 with low-pass transfer function $FT(p)$ is to be low enough that no self-excited oscillations occur in the two-point control circuit for synthesized signal z.

Should the circumstance frequently occurring in practical application that the connection between the measured substitute acceleration signal b_{EM} and the measured acceleration signal α_m is only incompletely described by the equation $\alpha_m = F_g(p) \cdot b_{EM}$ prove to be a source of disturbance for the quality of the two-

point cascade control, the process claimed for the invention is expanded. This expansion is characterized by the block diagram in Figure 3. In this instance the transfer function $FM(p)$ 9 describes the mechanical frequency response from the surface of the armature set in movement which is engaged by the thrust of the drive to the position of the part of the accelerometer set in movement at which the effect used for registration of acceleration is generated. The relationship between the substitute acceleration signal bEm and the measured acceleration α_m is accordingly expressed as $\alpha_m = FM(p) \cdot Fg(p) \cdot bEM$. This mechanical frequency response with transfer function $FM(p)$ 9 (see Figures 3 and 4) is now taken into account in that the high-pass filter 3 with high-pass transfer function $FH(p) = FT(0) - FT(p)$ $Fg(p)$ is replaced by a modified high-pass filter 10 with modified high-pass transfer function $Fh(p) = FT(0) - FT(p)$ $Fg(p) \cdot FM(p)$. It is advisable in this process not to determine the limit frequency of the low-pass filter 2 with low-pass transfer function $FT(p)$ until the high-pass filter 3 with high-pass transfer function $FH(p)$ has been replaced by modified high-pass filter 10 with modified high-pass transfer function $Fh(p)$.

Should the transfer function $FM(p)$ have a plurality of polar and/or zero positions, development of the high-pass filter 10 with modified high-pass transfer function $Fh(p)$ is found to be very costly. In order to reduce this cost in development of this high-pass filter 10, the process claimed for the invention may be further modified as described in the following. A part

$$F_0(p) = \frac{(1+p \cdot T_u) \cdot (1+2 \cdot D_v \cdot p \cdot T_v + p^2 \cdot T_v^2) \cdot \dots}{(1+p \cdot T_i) \cdot (1+2 \cdot D_j \cdot p \cdot T_j + p^2 \cdot T_j^2) \cdot \dots}$$

is separated from the transfer function of the mechanical frequency response. This part allows for one or more poles

and/or zero positions with particularly high values of $T\mu$, Tv , Ti , or Tj . The transfer function of the mechanical frequency response may be described as follows

$$F_M(p) = F_0(p) \cdot F_{M,\text{Rest}}(p) \text{ mit } F_{M,\text{Rest}}(p) = F_M(p) \cdot F_0^{-1}(p).$$

The mechanical frequency response with transfer function $F_M(p)$ is now taken into account only in approximation by the circumstance that the high-pass filter 3 with high-pass transfer function $FH(p) = FT(0) - FT(p)$ $Fg(p)$ is replaced by a modified high-pass filter 11 with modified high-pass transfer function $Fh^*(p) \approx F\gamma(0) - FT(p) F[-](p) F_0(p)$. It is advisable not to determine the limit frequency of the low-pass filter 2 with low-pass transfer function $FT(p)$ in this process until the high-pass filter 3 with high-pass transfer function $FH(p)$ has been replaced by modified high-pass filter 11 with modified high-pass transfer function $Fh^*(p)$. The proposed process claimed for the invention is described by the block diagram in Figure 4.

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